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A unique habitat of endolithic biota: hurricane-induced limestone rubble in an Albian sand-mass of the Cracow Upland, southern Poland

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ABSTRACT:

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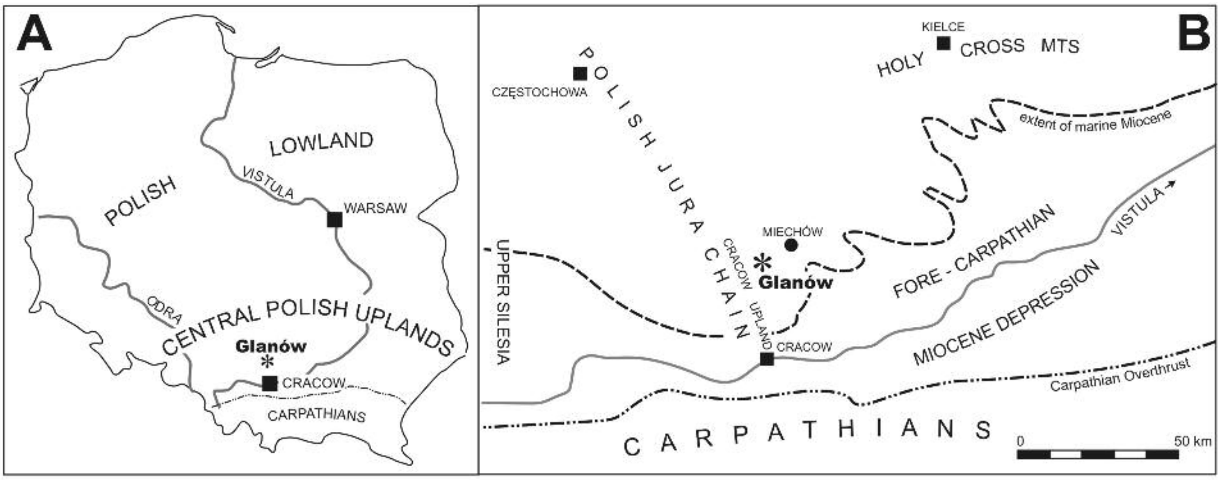
Peculiarly shaped, relatively large (up to 30 cm in diameter) concretions of quartzitic sandstone occur in a single horizon of Upper Albian loose sands in the Cracow Upland, southern Poland. They are characterized by hollow interiors adorned with mass-aggregated moulds of the borings of diverse sponges, polychaetes and bivalves. These moulds represent the siliceous filling of borings in limestone clasts that had been subject to dissolution, leaving a hollow within the concretion that had formed around them. Synsedimentary block-faulting and jointing affected the Jurassic limestone-basement, causing the uplift of a local horst (the Glanów Horst), to within the littoral zone so that it became exposed to abrasion. It is inferred that a hurricane or catastrophic storm surge swept limestone debris fallen from the cliff out to the sandy offshore, where nucleation of soluble silica was presumably favoured by the decay of the soft tissue of live or dead rock-borers. After filling the empty borings and solution of the limestone clasts, the nucleation progressed intensely, finally completed by precipitation of siliceous sinter in the hollow interiors of some of the concretions during subsequent diagenesis and/or epigenesis.

Key words: Concretions, Rock-borers, Synsedimentary block-faulting, Cretaceous, Albian, Cracow Upland, Poland.

INTRODUCTION

This paper reports on peculiar concretions of quartzitic sandstone occurring in the mid-Cretaceous transgressive sands exposed near Glanów in the northern part of the Cracow Upland, southern Poland (see Text-fig. 1). The concretions occur in the Sucha section, in unit 3 of a 33 m thick series of nearly unfossiliferous, poorly glauconitic, locally silicified Upper Albian quartz sands (Text-fig. 2) (Marcinowski 1974, fig. 27; Marcinowski and Radwański 1989, fig. 7). The siliceous cementations take the form of irregular lenses or more or less spherical bodies (up to 30 cm in diameter), most of which are hollow. The quartzitic sandstone concretions look at first sight to be exotic bodies within almost loose sand. In the early 1970s they were well exposed in a temporary rural sand-pit at Sucha (see Text-fig. 3; sections 109–109a and figs 13 and 14 in Marcinowski 1974), which yielded all the specimens described in this study. They were first reported by Marcinowski (1974, p. 139 and pl. 17, fig. 9).



Text-fig. 1. Location of the study area in: **A** – Poland; **B** – Cracow Upland within the range of the Central Polish Uplands, to show the position of the Glanów Horst (see Text-figs 3-4) and the Upper Albian sandy sequence exposed at Sucha

The peculiarity of the concretions concerns the following features:

The ubiquity of moulds of diverse borings which protrude into the hollow interiors;

The origin of the hollow interiors as a result of dissolution of rock-bored limestone debris

The transport of the limestone clasts from the rocky shore to the surrounding sandy basin as a single event.

These peculiar features require a discussion of the dynamic events that controlled an occasional supply of limestone debris from the otherwise inaccessible limestone-built rocky shore. When exposed along the wall of the Sucha sand-pit, the concretions appeared like cliff boulders of a rocky seashore.

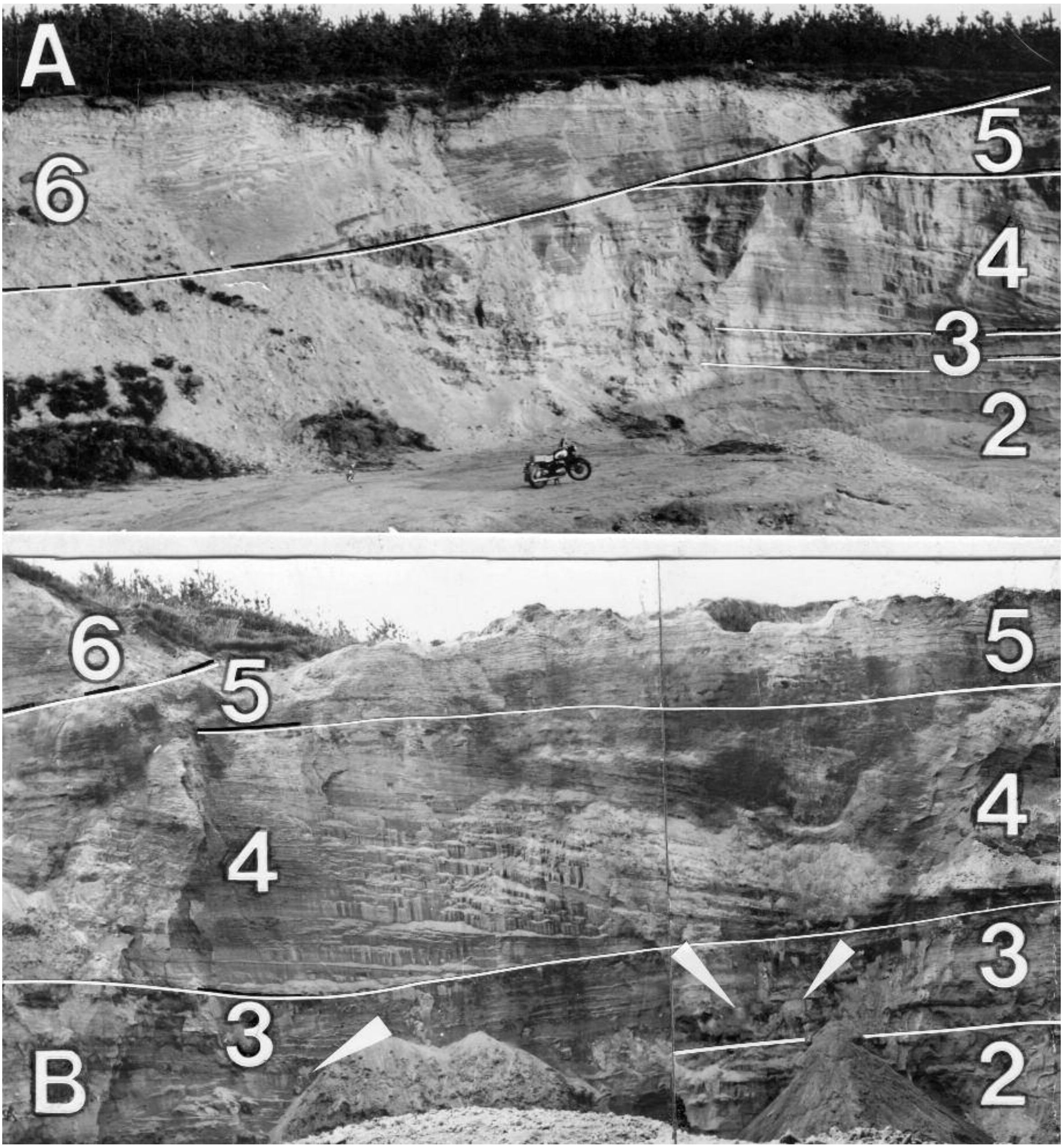
REGIONAL SETTING

In the Polish Jura Chain, with the Cracow Upland at its south-eastern tip (see Text-fig. 1B), the Upper Albian through Turonian transgressive sequence (see Marcinowski 1970a, 1974; Marcinowski and Szulczewski 1972; Marcinowski and Radwański 1983, 1989) rests upon an Upper Jurassic substratum. This substratum, of Middle/Late Oxfordian to Early Kimmeridgian age, is composed of biohermal (sponge-cyanobacterial) massive limestones laterally interfingering or alternating with bedded (platy) limestones; the latter locally contain allodapic (turbiditic) limestone intercalations (see Marcinowski 1970b; Matyszkiewicz 1996, 1997 and references cited therein; Ziółkowski 2007). The biohermal limestones were more resistant to weathering in post-Jurassic time (Neocomian to Early/Middle Albian) and usually formed hummocks (monadnocks) in the diverse topography over which the mid-Cretaceous transgression took place. As a result, the mid-Cretaceous transgressive sequence, composed mostly of quartz sands, ranges in thickness from over 50 metres in basinal settings to nil upon topographic highs (Marcinowski 1970a, 1974). Upon the hummocks of biohermal limestones, the transgressive sequence begins with sands, usually glauconitic, of Cenomanian age (see Marcinowski 1970a, figs 2–4; Marcinowski 1974, fig. 2). Moreover, the synsedimentary block-faulting appears (Marcinowski 1974) to have been intensely active, propagating southeastwards towards the Cracow Upland (see Text-fig. 1B), where not only Cenomanian, but also Turonian and younger (up to and including Santonian) sequences rest directly upon the Jurassic substratum (see Dżułyński 1953, pp. 392-393 and references cited therein; Alexandrowicz 1954; Barczyk 1956; Marcinowski and Szulczewski 1972, figs 2, 6; Marcinowski 1974, figs 23–29; Walaszczyk 1992).

In this context, it is evident that the horsts of Jurassic limestones exposed around Glanów (see Marcinowski 1974, fig. 12; and Text-fig. 3 herein) are elements of the mid-Cretaceous topography (see also Text-fig. 4) that have been exhumed from their Late Cretaceous and Tertiary cover, and thus have no connection with the Tertiary large-scale block-faulting of the Cracow Upland (see Dżułyński 1953) that preceded the Miocene transgression (see Radwański 1968).

THE LIMESTONE DEBRIS

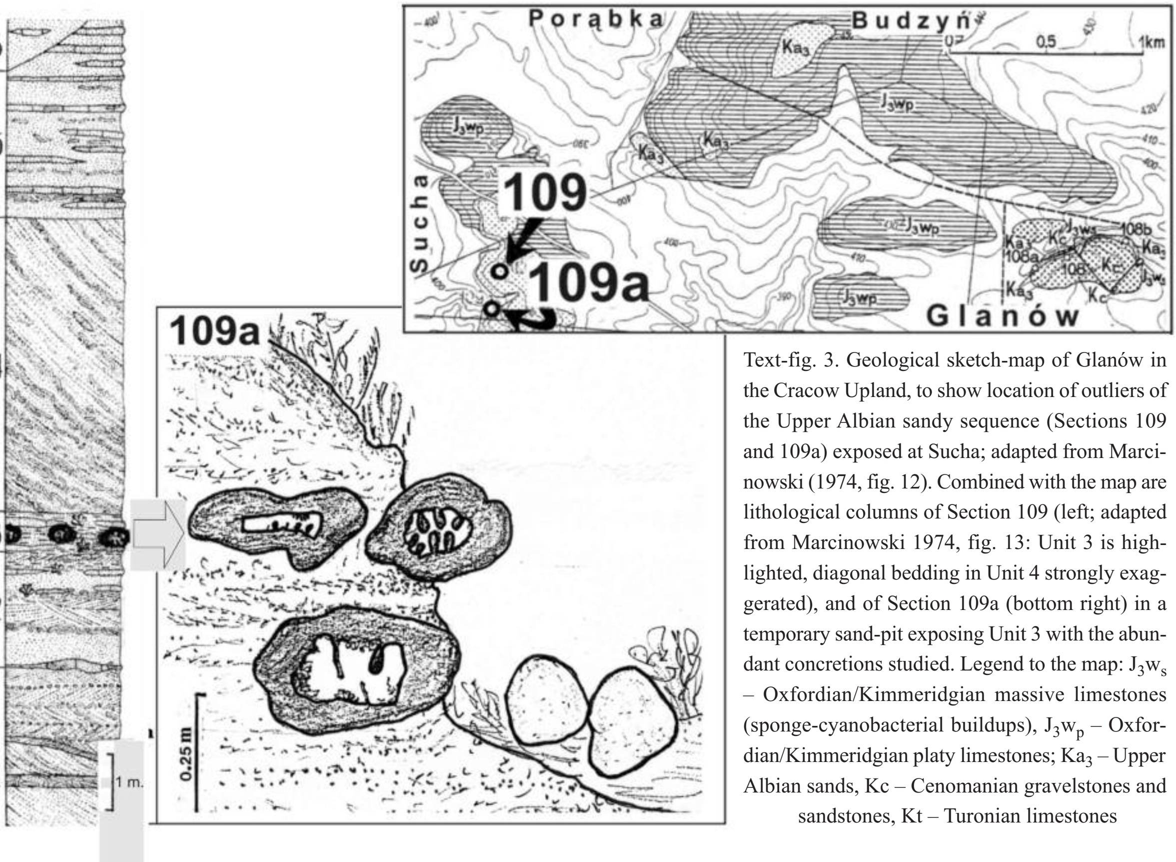
The siliceous moulds of borings on the interior surface of the hollow quartzite sandstone concretions pro-



Text-fig. 2. Mid-Cretaceous sequence in the Cracow Upland, as exposed at Sucha near Glanów (Section 109; see Text-fig. 3): Upper Albian cross-bedded, poorly glauconitic sands with diverse sponges and trace fossils, locally cemented into irregular lenses and concretions of siliceous sandstones: **A** – Eastern wall of sand-pit, to show a subtidal channel (unit 6); **B** – Southern wall of sand-pit; arrows indicate some of the larger concretions. Adapted from: Marcinowski (1974, fig. 14) and Marcinowski and Radwański (1983, pl. 2, figs 2a, 2b)

vide evidence that the hollows resulted from the dissolution of clasts of pure limestones, of which no residue has been left. Such pure limestones are those of Oxfordian/Kimmeridgian biohermal buildups (J_3w_s in Text-fig. 3). In some hollows, a scanty clayey residue remains, indicating its origin from the slightly marly admixture that is typical of the Oxfordian/Kimmeridgian platy limestones (J_3w_p in Text-fig. 3). In exceptional cases, pieces of the less calcareous platy limestones have been preserved undissolved in some of the concretions (see Text-fig. 5).

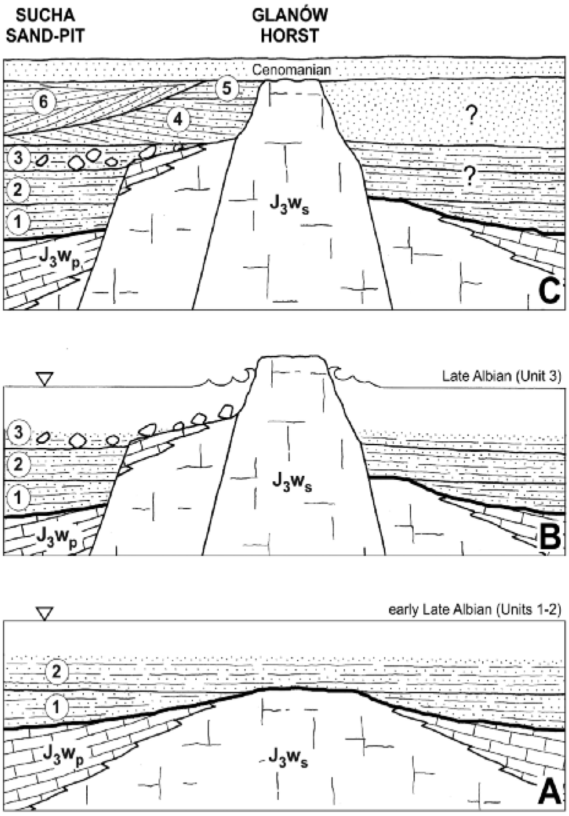
Regardless of the lithology, it is the shape of the limestone clasts composing the debris that is significant. Those from platy limestones are brick-like, not having been rounded/abraded to any extent (see Text-figs 5A and 13A); some are rounded on one side (see



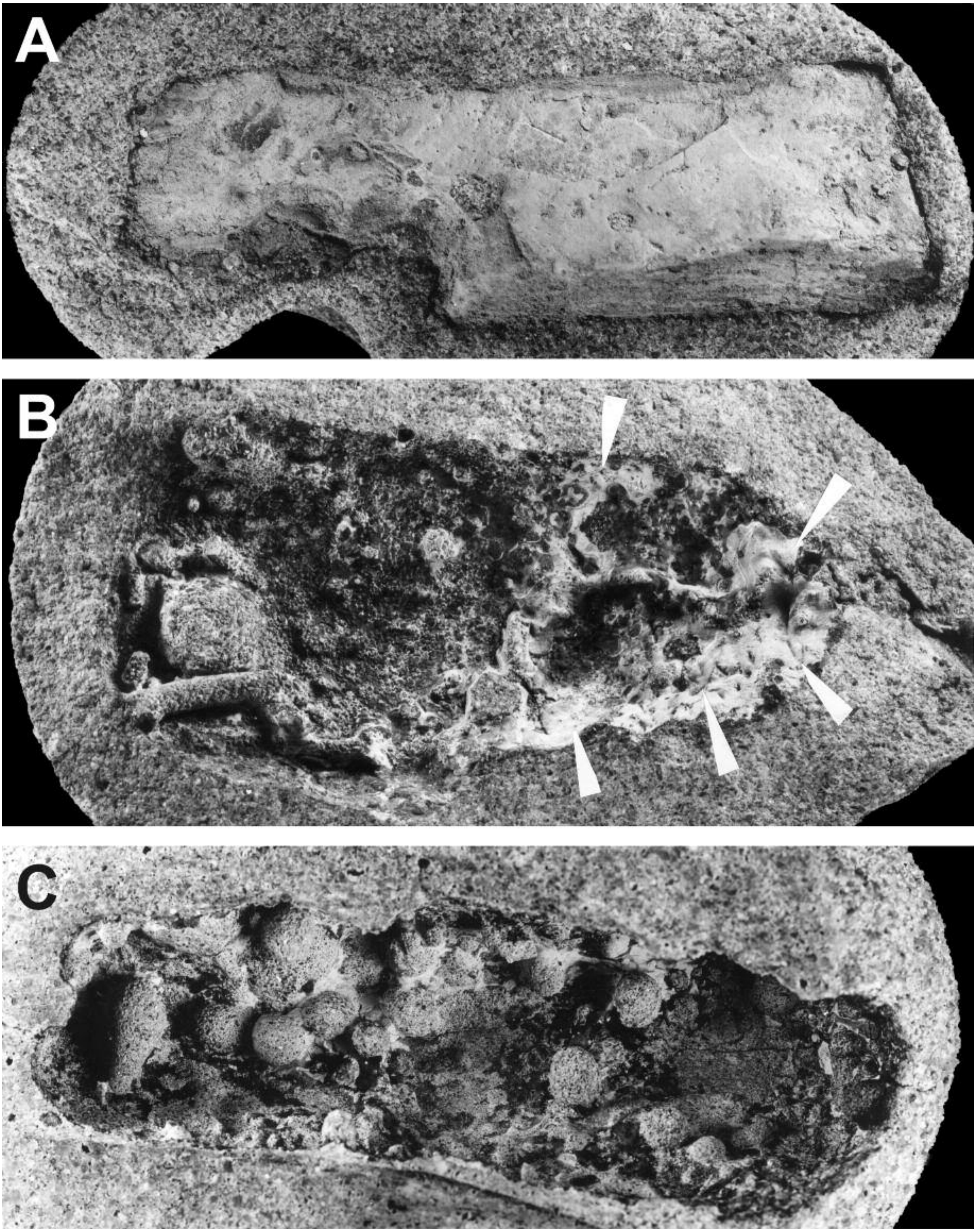
Text-fig. 3. Geological sketch-map of Glanów in the Cracow Upland, to show location of outliers of the Upper Albian sandy sequence (Sections 109 and 109a) exposed at Sucha; adapted from Marcinowski (1974, fig. 12). Combined with the map are lithological columns of Section 109 (left; adapted from Marcinowski 1974, fig. 13: Unit 3 is highlighted, diagonal bedding in Unit 4 strongly exaggerated), and of Section 109a (bottom right) in a temporary sand-pit exposing Unit 3 with the abundant concretions studied. Legend to the map: J_3w_s – Oxfordian/Kimmeridgian massive limestones (sponge-cyanobacterial buildups), J_3w_p – Oxfordian/Kimmeridgian platy limestones; Ka_3 – Upper Albian sands, Kc – Cenomanian gravelstones and sandstones, Kt – Turonian limestones

Text-fig. 5B) or along the corners (see Text-fig. 5C). Those from massive limestones are irregularly shaped, quite often with more or less angular fragments (see Text-figs 6A, 6B, 10A, 13B). Well-rounded clasts are subordinate. The size of particular limestone components is variable, ranging from only a few centimetres to a maximum of 15 cm. A very indistinct roundness distinguishes all limestone debris recognized from those typical (see Radwański 1969, 1970) of the mature sea cliffs.

In the Glanów area, the biohermal (J_3w_s) and platy limestones (J_3w_p) co-occur within the limestone debris, their presence indicating a deeper erosion of the Upper Jurassic substratum. Consequently, it is thought that the shore abrasion supplying the limestone debris was very short-termed, almost episodic, but of sufficient duration for profuse colonization by rock-borers. The commencement of littoral abrasion and appearance of rock-borers is ascribed to uplift of the Jurassic substratum and its protrusion above the widespread Al-

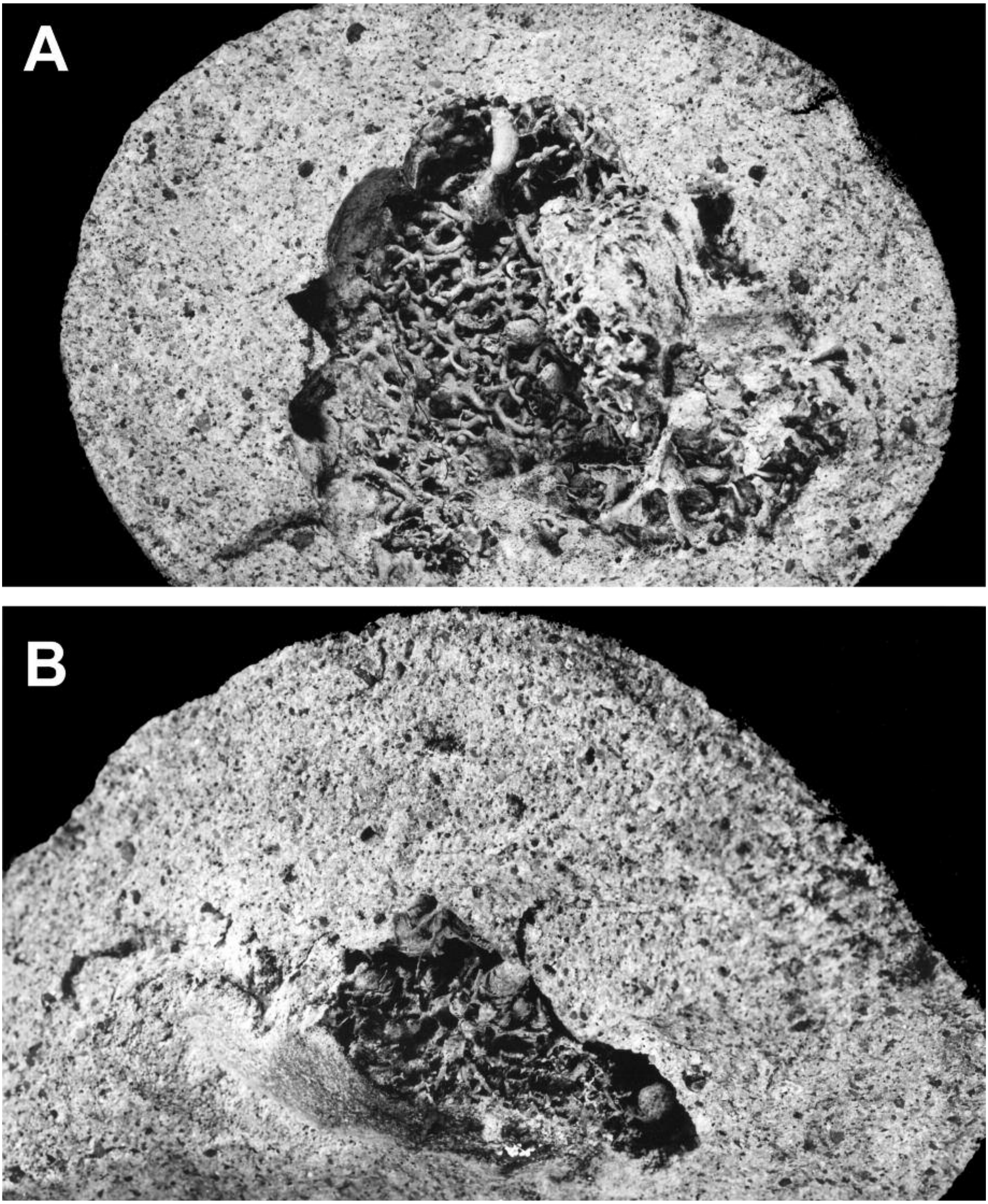


Text-fig. 4. Mid-Cretaceous dynamic events resulting from Late Albian synsedimentary block-faulting, and the resultant delivery of Oxfordian/Kimmeridgian limestone debris [J_3w_s – massive (biohermal), J_3w_p – platy; cf. Text-fig. 3] to the sandy basin in which the Albian through Cenomanian sequence has formed bian sandy sediments then being deposited. This uplift was due to synsedimentary block-faulting throughout the region (see Marcinowski 1974), which gave rise to the Glanów Horst (see Text-fig. 4).



Text-fig. 5. Clasts of Oxfordian/Kimmeridgian platy limestones, as preserved in concretions: **A** – Slab of a marly variety in plan view, to show the rectangular (orthogonal) jointing; the slab neither abraded nor infested by rock-borers, nat. size; **B** – Hollow after a partly abraded slab (right), containing several borings and draped by siliceous sinter (arrowed), nat. size; **C** – Hollow after a slab abraded along the corners and containing scarce borings of two generations: older of bivalves (deeply abraded), and younger of sponges, intact (lower right), × 1.5

Furthermore, the angularity of the limestone debris, which is especially well pronounced in rectangular, brick-like pieces (see Text-fig. 5A), relates to the orthogonal joint system. The jointing observed today in the Jurassic limestones of the Glanów Horst should thus be ascribed, partly at least, to the mid-Cretaceous block-faulting tectonics. The relationship of the jointing in the Glanów area to the post-Cretaceous (pre-Miocene)



Text-fig. 6. Hollow after clast of Oxfordian/Kimmeridgian massive (biohermal) limestone, densely riddled by rock-borers: **A** – clast located centrally, with relatively thin coating of a smaller-sized concretion, × 1.5; **B** – Smaller clast located eccentrically in a larger concretion, × 2 (for close-up see Text-fig. 13B) large-scale Alpine regional block-faulting throughout the Cracow Upland (see Dżułyński 1953, Radwański 1968) is beyond the scope of the present report.

THE ORIGIN OF THE CONCRETIONS

The origin and growth of the concretions were certainly connected with the release of silica from siliceous sponges, the remnants of which (silicified mummies or their fragments) are common in some intervals of the Upper Albian sequence (see Marcinowski 1974, pp. 138, 139 and figs 13–15; Marcinowski and Radwański 1989, p. 163). It is assumed that the presence of the organic tissue of live or dead rock-borers in the limestone debris accelerated the precipitation of the silica. However, the rock-bored limestone clasts, after the empty borings had become filled with silica, were not ideal centres of precipitation, because in some concretions the clasts are located eccentrically (see Text-fig. 6B) or nearly at the margin of the concretion (see Text-fig. 10A); on the other hand, some concretions are 'barren', that is devoid of any object inside. The rock-bored clasts are always coated completely by the precipitated silica, and never extend outside the concretion.

The silica solution also percolated through the sand after the dissolution of the limestone clasts and the resultant formation of the hollow concretions, since in some of them a siliceous sinter in the form of minute dripstones was deposited on the interior surface (see Text-figs 5B, and 10A, at right). Irregular/lenticular cementations in the sand also formed at that time and terrestrial wood became silicified (see Marcinowski 1974, p. 138).

Finally, ubiquitous growth of the concretions in a single region (see Text-fig. 3; Section 109a of Marcinowski 1974) was generated by local delivery of the rock-bored limestone debris. In the case of limestone clasts that had not been infested by rock-boring organisms before transport, the limestone would have been completely leached out, leaving no trace of its former presence. The soluble silica would become dispersed throughout the sedimentary sequence to precipitate haphazardly in irregular cementations of sand, or even in fractures of the lithified sandstone (see Marcinowski 1974, p. 138) during further stages of diagenesis and/or epigenesis.

THE ROCK-BORERS

The borings, the moulds of which protrude from the walls of hollows inside the concretions (see Text-figs 5C and 6–13), are comparable to those of present-day sponges, polychaetes and bivalves (Marcinowski 1974, p. 139). Of these rock-borers, the sponges, polychaetes and bivalves recognized herein, bore exclusively in limestones (see Radwański 1968, 1969, 1970). These borings prove that the objects bored were limestone pieces which subsequently became nuclei of the siliceous concretions.

The taxonomy of the borings remains uncertain, as discussed below.

A situation in which all the biotic elements of a sequence are exclusively moulds of borings is not exceptional in the geological record. Such were reported, for instance, from the Cenomanian Woodbine Formation of Texas, USA (Stephenson 1952), the Oligocene–Miocene Bluff Formation of Grand Cayman, British West Indies (Pleydell and Jones 1988) and the Plio-Pleistocene (? Calabrian) sequence of southern Italy (Bromley and D'Alessandro 1987).

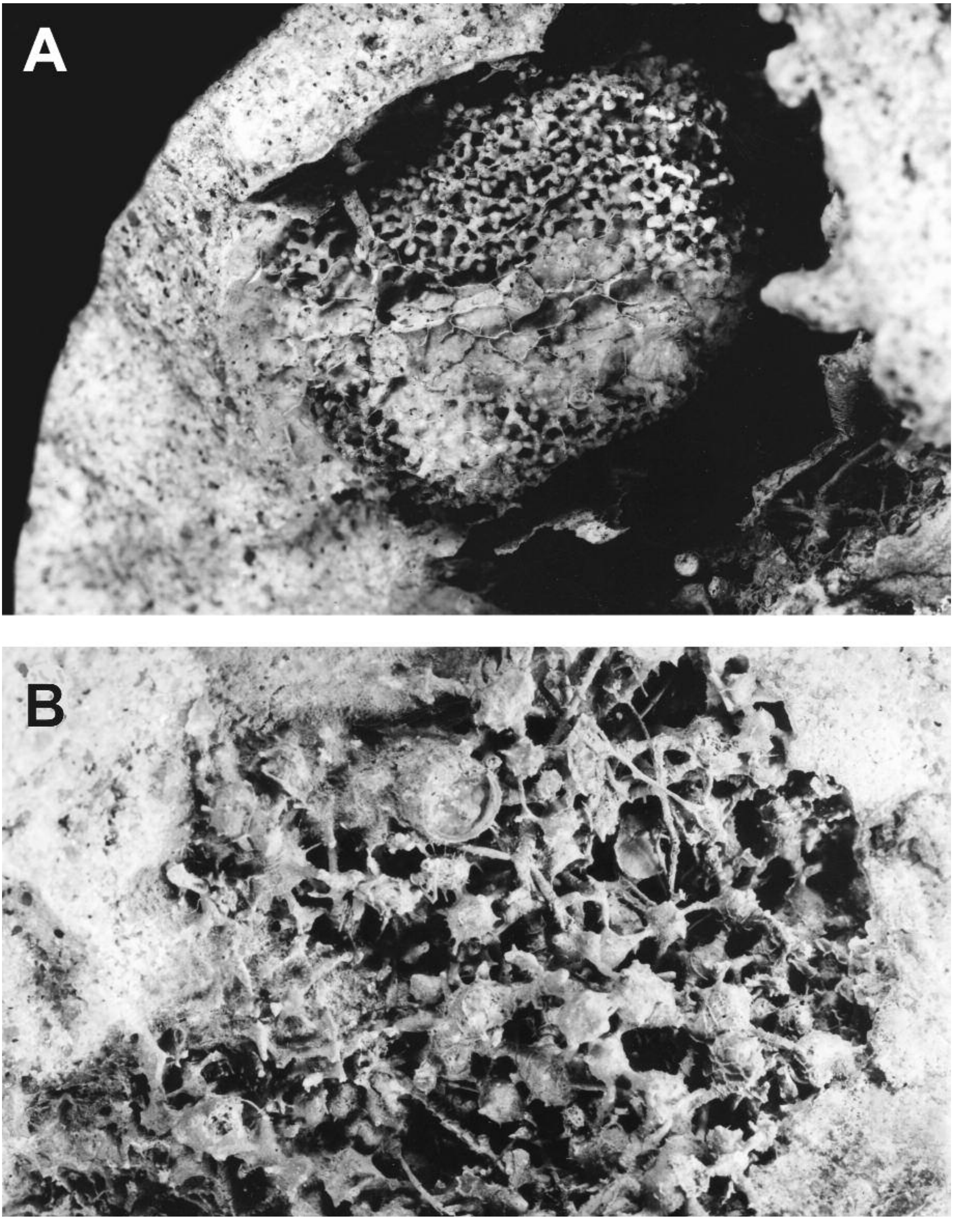
In the material studied, the bivalves bored the limestone clasts superficially (see Text-fig. 12A), whereas the sponges and polychaetes riddled the clasts completely, to produce a 'three-dimensional' maze of borings that filled the space of hollows almost totally (see Text-figs 7–10). All these rock-borers seem to have been in action at more or less the same time (see Text-figs 13A-B), and no distinct cross-cutting of borings may be found. Many borings, however, especially those of bivalves, have subsequently been abraded to a variable extent (see Text-figs 5C, 10A', 12A, 12B, 13A, 13B). Two successive generations of borings may be recognized in some cases (see Text-fig. 5C).

Rock-boring sponges

The moulds of borings of ancient clionid sponges (family Clionidae Gray, 1867) are commonly referred to the ichnogenus *Entobia* Bronn, 1837, the ichnospecies of which are more or less comparable to borings of present-day species, especially those of the Mediterranean (see e.g., Volz 1939, Rützler and Bromley 1981, Bromley and D'Alessandro 1989). Three ichnospecies are distinguishable in the material studied: *Entobia geometrica*, *E. magna*, and *E. parva* (see Text-figs 7, 8).

Entobia geometrica Bromley and D'Alessandro, 1984, is characterized by subangular chambers, all connected by intercameral canals. The specimens collected (see Text-fig. 7B) are nearly identical with the holotype (see Bromley and D'Alessandro 1984, pl. 18, fig. 1) from the Upper Pliocene of southern Italy.

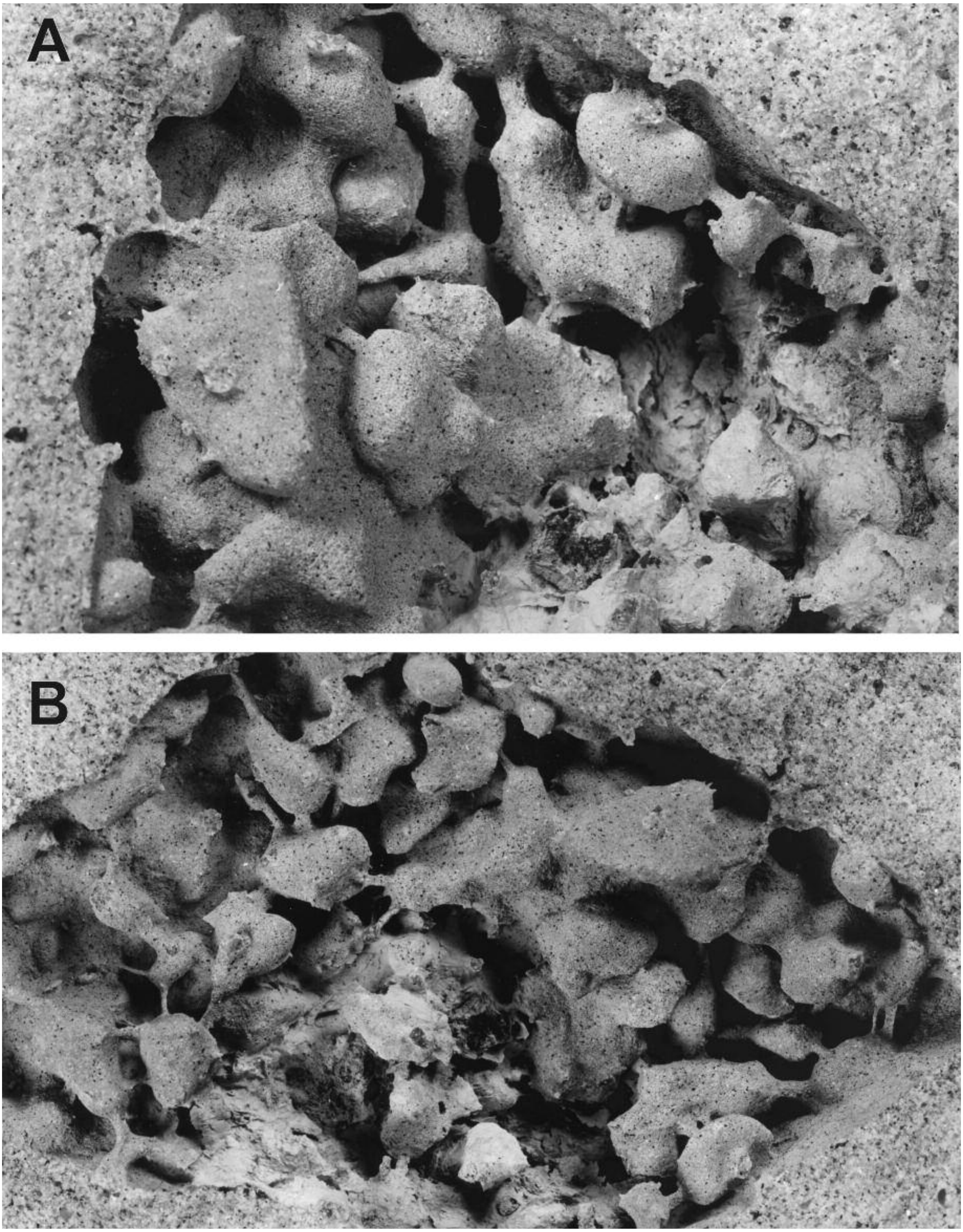
Entobia magna Bromley and D'Alessandro, 1989, is characterized by very large (10–20 mm), flattened, irregularly shaped, isolated or fused chambers, of variably sized within a network. The specimens collected (see Text-figs 8A, 8B and 9) are nearly identical with the holotype from the Pleistocene of the Island of Rhodes, Greece (see Bromley and D'Alessandro 1989, pl. 27, fig. 5). This ichnospecies corresponds to the borings of the present-day clionid, *Cliona rhodensis* Rützler and Bromley,



Text-fig. 7. Moulds of clionid sponges, classified in ichnological nomenclature: **A** – *Entobia parva* Bromley and D'Alessandro, 1989, × 4; **B** – *Entobia geometrica* Bromley and D'Alessandro, 1984, × 4

1981, from the Rhodes coast (see Rützler and Bromley 1981, fig. 1b; Bromley and D'Alessandro 1989, figs 5, 6).

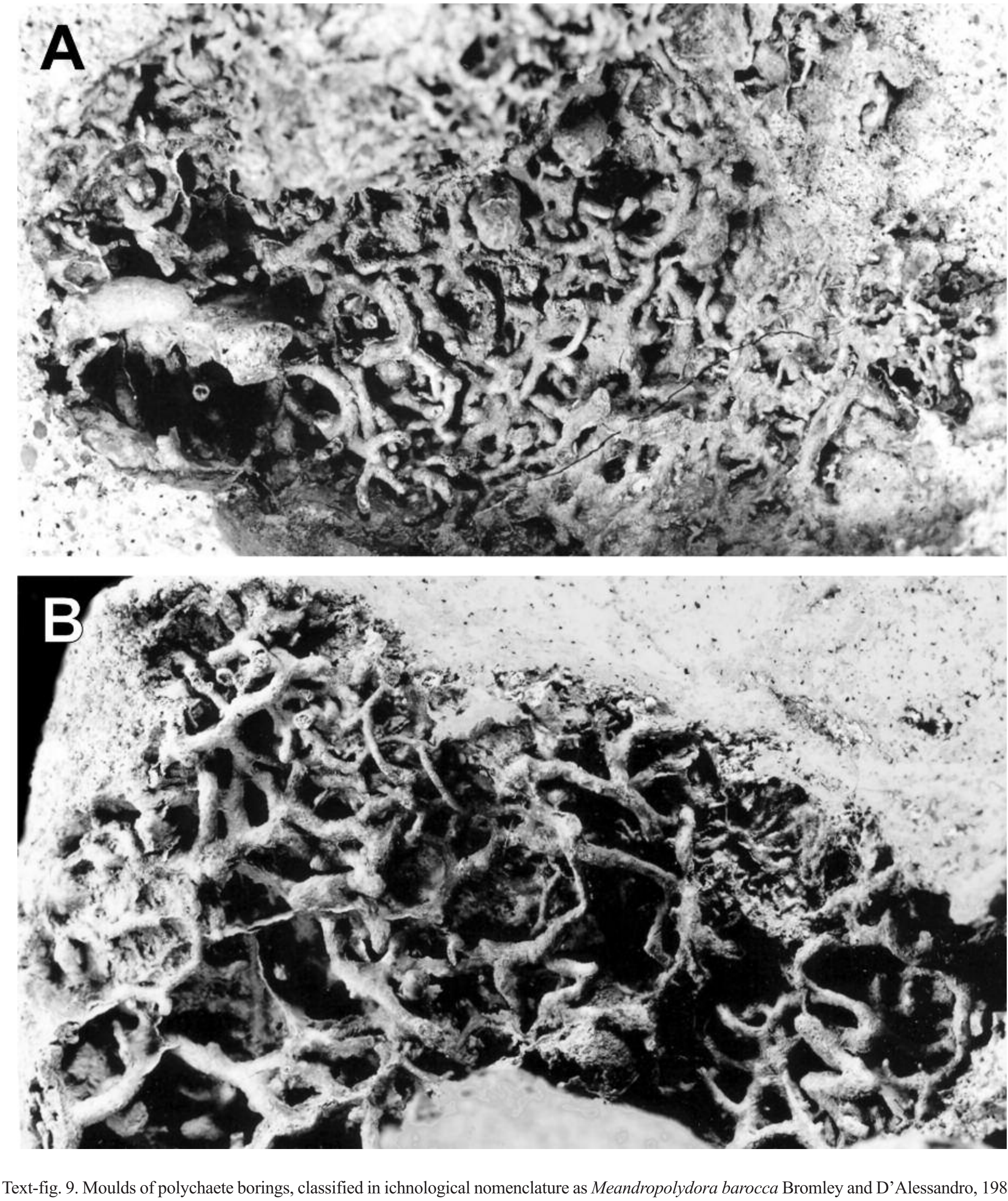
Entobia parva Bromley and D'Alessandro, 1989, is characterized by a small-sized network of densely packed, minute chambers connected by enlarged



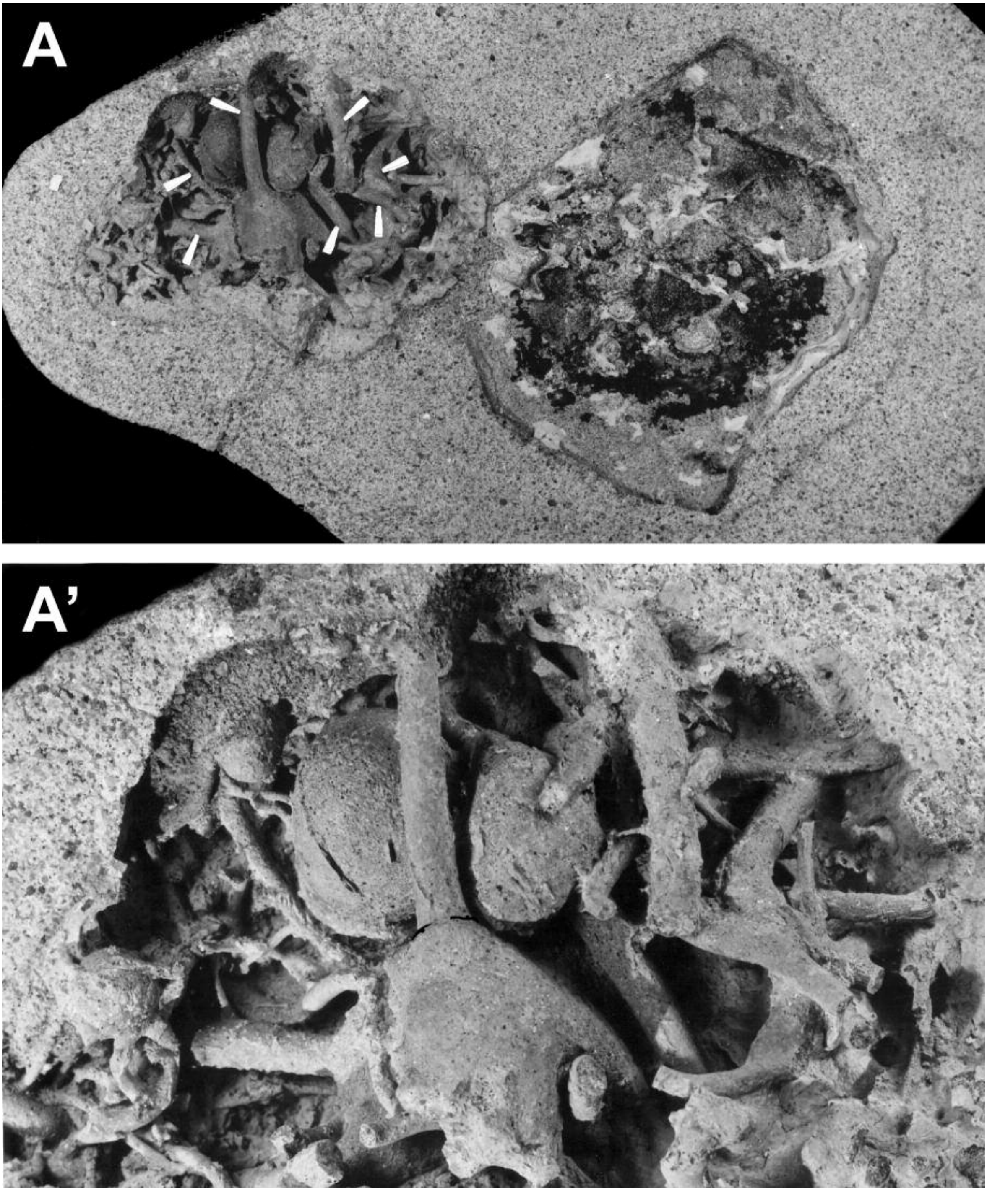
Text-fig. 8. Moulds of clionid sponges, classified in ichnological nomenclature: **A**-**B** – *Entobia magna* Bromley and D'Alessandro, 1989; A × 2, B × 1.5

(thick) intercameral canals. The few specimens collected (see Text-fig. 7A) are almost identical with the paratype from the Upper Danian of Limhamn Quarry near Malmö, southern Sweden (see Bromley and D'Alessandro 1989, pl. 28, fig. 5). The whole network is space-compact, sharply outlined; as stated by Bromley and D'Alessandro (1989, p. 289), its growth front is abrupt and closed. All these features suggest that this ichnospecies counterparts the borings of present-day clionids of the genus *Cliothosa* Topsent 1905 (see Volz 1939, pl. 4, fig. 3) as well as their Miocene representatives (see Radwański 1964, pl. 1, figs 5, 6; 1969, pl. 2, figs 3, 4).

The sponge ichnotaxa recognized are more com-



Text-fig. 9. Moulds of polychaete borings, classified in ichnological nomenclature as *Meandropolydora barocca* Bromley and D'Alessandro, 1987: **A** – Network of larger forms, **B** – Network of smaller forms; both × 3 parable to those of Cenozoic rocky shores (see Radwański 1964, 1969; Bromley and D'Alessandro 1984, 1989) than to those of the Cretaceous. Such an oddity may result, partly at least, from the development of the forms studied in limestone rock debris, instead of in the limited space offered by shells, as in the case of almost all Cretaceous occurrences (see e.g., Stephenson 1952, Bromley 1970).

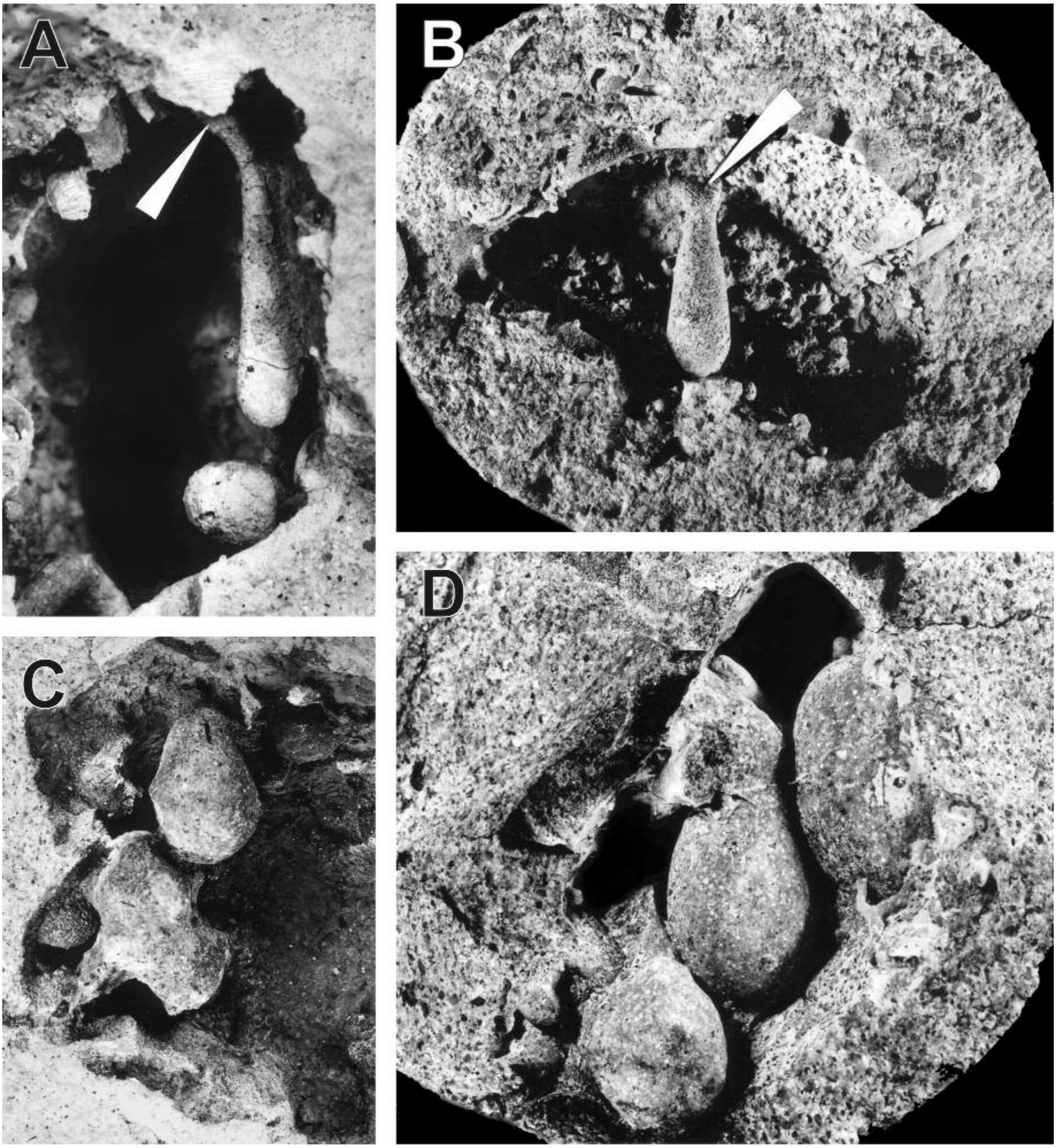


Text-fig. 10. Moulds of rare polychaete borings, classified neontologically as *Potamilla* sp.: **A** – General view of the hollow yielding such borings (arrowed), near the margin of a larger concretion (left); adjacent is another hollow, devoid of borings, but draped with siliceous sinter (cf. Text-fig. 5B), nat. size; **A'** – Close-up of the hollow, to show *Potamilla* borings subordinate to other borings, including the pear-shaped borings of bivalves (see Text-figs 11C-11D), × 2.5

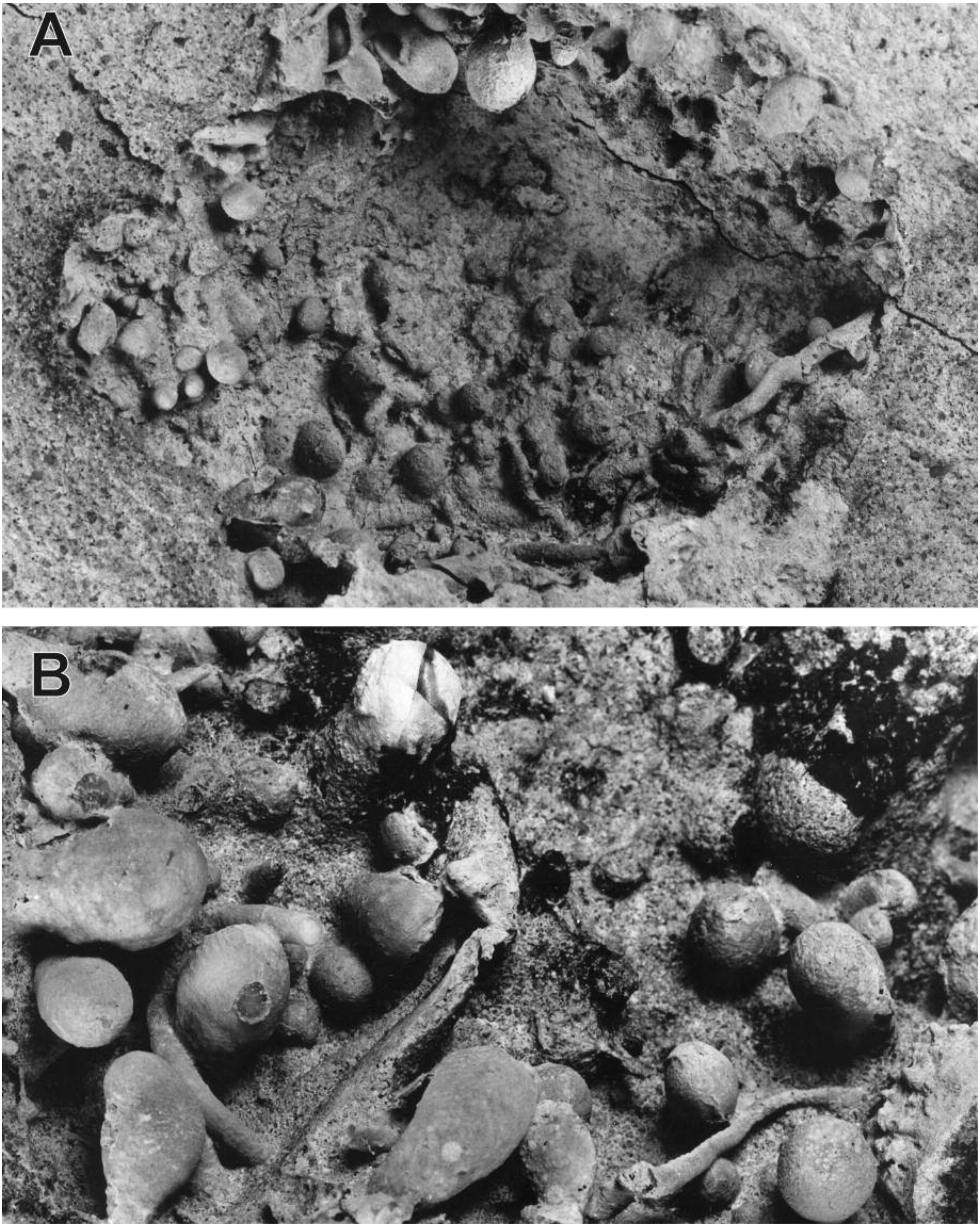
Rock-boring polychaetes

The classification of ancient polychaete borings was undertaken by Bromley and D'Alessandro (1983, 1987), who revised the previous ichnogenera, emended their diagnoses, and established some new ichnospecies. Moreover, they introduced the idea of an 'ontogenetic series' that comprises different ichnotaxa not only of specific, but also of generic rank (see Bromley and D'Alessandro 1987, fig. 16). As a result, the synonymy of particular ichnotaxa has become extremely complex (see Bromley and D'Alessandro 1983, p. 287; 1987, pp. 403 and 406), so that it includes taxa classified formerly quite differently (see Radwański 1964, 1968, 1969, 1970; Głazek, Marcinowski and Wierzbowski 1971).

According to the classification of Bromley and D'Alessandro (1987), the majority of specimens studied (see Text-figs 9, 10) belong to the ichnogenus *Me-*

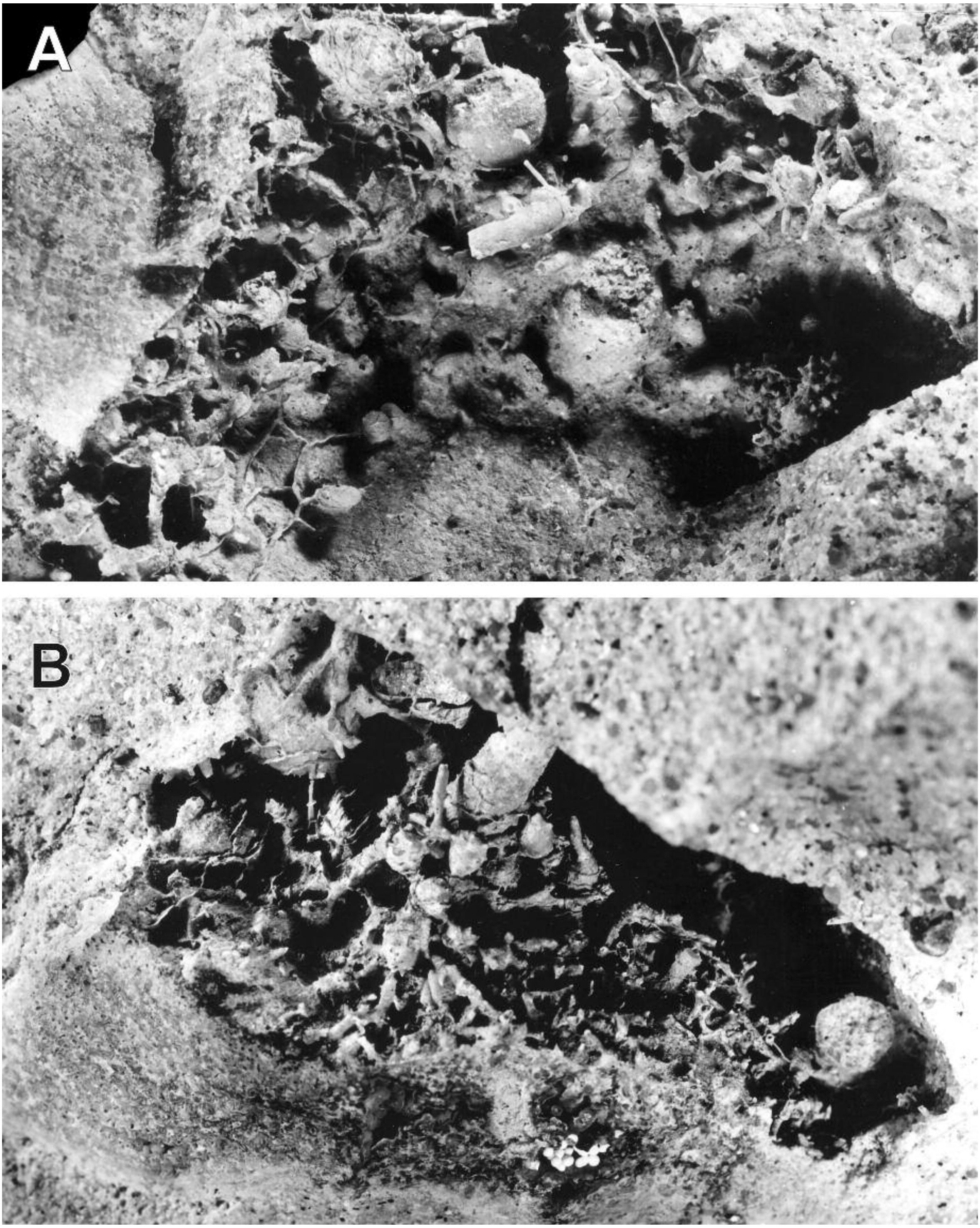


Text-fig. 11. Moulds of bivalve borings: **A-B** – Flask-shaped, with the siphonal neck and figure 8-shaped aperture (arrowed) preserved; A – Boring formed at margin of larger clast devoid of gregarious rock-borers, × 1.5; B – Single boring in a small clast, nat. size; **C-D** – Pear-shaped, abraded, having been formed in an exceptionally small clast, both × 1.5; Further explanation or discussion in the text *andropolydora* Voigt, 1965, established for borings in Late Cretaceous oysters. A maze-like network of borings in the material studied is best comparable with that of the ichnospecies *M. barocca* Bromley and D'Alessandro 1987, especially with its holotype and one of the paratypes, both from the Pliocene of south-



Text-fig. 12. Moulds of partly abraded borings of supposedly diverse bivalves: **A** – Riddling part of a clast , and associated with those of *Potamilla* (cf. Text-fig. 10A'), × 1.5; **B** – Riddling gregariously all over a clast, also associated with those of *Potamilla* (cf. Text-fig. 10A'), × 3; Further explanation or discussion in the text ern Italy (see Bromley and D'Alessandro 1987, pl. 40, fig. 1 and pl. 44, figs 1-2).

A small part of the specimens studied (see Text-figs 10A' and 12A, 12B) is identical with forms from the Cenomanian of the Cracow Upland (Głazek *et al.* 1971, p. 439, fig. 2d, e and pl. 2, figs 1a-b) classified previ-



Text-fig. 13. Diversity of the coeval activity of the rock-borers, as recorded by the moulds of their borings, primarily of sponges (cf. Text-fig. 7B) and polychaetes (cf. Text-figs 9-10) dominating over bivalves (cf. Text-fig. 12): **A** – Within a rectangular slab of platy limestone, **B** – Within an irregular clast of massive (biohermal) limestone (close-up of Text-fig. 6B); both × 4 ously as "*Potamilla*" type B; borings, which are indistinguishable from those produced by the extant genus *Potamilla* Malmgren, 1867 (see Radwański 1969, pp. 11, 12 and fig. 2A, 2B).

Rock-boring bivalves

The moulds of two bivalve borings (see Text-figs 11, 12) have long involved confusion concerning their attribution to definite taxa of either body- or trace-fossils.

The first one, represented by a single boring (see Text-fig. 11B) and repeatedly illustrated earlier (Marcinowski 1974, pl. 17, fig. 9; Marcinowski and Radwański 1989, fig. 9), is classified as "*Gastrochaena* sp.", understood as produced by a representative of the bivalve genus *Gastrochaena* Spengler, 1783. The borings of this type are more or less elongated and flask-shaped, with a well defined siphonal neck and a figure 8-shaped aperture (see Text-figs 11A, 11B, arrowed). Completely preserved specimens resemble in shape the extant bivalve genus *Penitella* Valenciennes, 1846 (see Röder 1977, fig. 17), of the family Pholadidae Lamarck, 1809, rather than any *Gastrochaena*.

The second one is represented by bulbous, pear-shaped borings (see Text-figs 11C-11D) that are morphologically identical with the extant bivalve genus *Aspidopholas* Fischer, 1887 (see Radwański 1969, 1977). Such borings from the Cenomanian of the Cracow Upland were formerly referred to the extinct bivalve genus *Myopholas* Douvillé, 1907 (Głazek *et al*. 1971, p. 442 and pl. 2, fig. 5).

It is not possible to determine the producers of the deeply abraded bivalve borings in the concretions (see Text-figs 5C, 10A' and 12, 13). The gregarious, smallest-sized specimens (see Text-fig. 12A) may belong to any of the above-mentioned taxa or even to any of the *Gastrochaena* known from the phosphatized driftwood from the Albian sands of Poland (Marcinowski and Radwański 1983, pl. 4, fig. 5).

Following the taxonomic treatment presented above, and in agreement with the idea of a neontological interpretation of ancient bivalve borings (Radwański 1964, 1969, 1977), no attempt is herein used to include all 'clavate' borings in the ichno-'pocket genus' *Gastrochaenolites* Leymerie, 1842, and its diverse morphospecies (see Kelly and Bromley 1984; Bromley and D'Alessandro 1987, pp. 394, 395).

THE DEPOSITION OF THE LIMESTONE DEBRIS

It is clear that the origin of the limestone debris on the shore of the Glanów-Horst shore did not directly lead to their deposition in the Cretaceous sedimentary sequence. The formation and deposition of the debris had to be separated by the timespan needed for the activity of the rock-borers. The intense bioerosion of the limestone, combined with physical abrasion (evidenced in bivalve borings), indicates that the rock debris remained on the shore for a relatively long time. The sweeping of this material out to sea from the shore, however, happened only once, when rough-water conditions became violently established.

The densely bored limestone debris at the Glanów Horst is very similar to, if not identical with that of the Miocene (Badenian) rocky shores of the Central Polish Uplands (see Radwański 1964, 1969, 1970), or the Pliocene and/or Plio-Pleistocene shores in various regions of the Mediterranean (see e.g. Bromley and Alessandro 1987, Martinell and Domènech 1995, De Gibert *et al*. 1998). The greatest similarity is shown by the Plio-Pleistocene (? Calabrian) succession of the Vallone Impis locality in southern Italy (Bromley and D'Alessandro 1987, p. 415, figs 18, 19), which shows a single horizon of giant, bioeroded limestone blocks in a sand-mass, interpreted as generated by synsedimentary movement along a nearby fault in the limestone basement.

In the Sucha section, it is not possible to determine the agent of transport and final deposition of the rock-bored limestone debris to the sandy sequence (unit 3 in Text-figs 2, 3).

The basin area of Sucha, to where the limestone debris was transported, represented a widespread subtidal zone (Marcinowski 1974, p. 189), where a deep, trough-like channel (? tidal creek) was finally formed (Unit 6 in Text-fig. 2). The removal of coarse limestone debris from the cliff was evidently due to a high-energy agent, able to carry heavy stones (up to 15 cm in diameter) far offshore. If a cliff at the Glanów Horst was the source, then the limestone debris was transported for at least one kilometre (cf. Text-fig. 3). A violent hurricane/catastrophic storm surge and removal of limestone debris from the nearshore zone best explain these unusual structures (e.g., for Unit 3; see Text-figs 2, 3). Hurricanes, with an onshore wind, may cause a rise in sea level several metres above normal (see Reading and Levell 1996, p. 12) and offshore sediment transport for as much as 25-40 kilometres (see, e.g., Handford 1986, Aurell *et al*. 1995).

Apart from a violent hurricane/storm surge, an action of waves involved by a successive pulse of the block-faulting synsedimentary tectonics (?earthquake at the shore, including mass movement) may also be taken into account. Such transport was able to disperse evenly the cliff-borne rubble over the offshore sand-mass (Unit 3 in Text-fig. 2).

During Late Albian the northern part of the Cracow Upland, the Glanów Horst including, was a marginal part of the epicontinental Central European Basin without direct connection with the tectonically mobile West Carpathians Basins in the South, which were a part of the Northern Tethys (see Marcinowski 1974, p. 193; Marcinowski and Wiedmann 1988, figs 1C, 8B). Such geotectonic position of the Glanów Horst during Late Albian precluded the rise of an oceanic tsunami. Nevertheless, it is known a case of tsunami transportation which produced the final deposit similar to that reported at the Glanów Horst. This is supplied by the Boca-do-Rio section in a river mouth (estuarium) in Algarve, southern Portugal. In this section (see Matrques Da Silva *et al*. 1996, fig. 2), within a sequence of silty clays there appears a horizon of the cliff-borne, rock-bored limestone rubble (up to 40 cm in diameter), interpreted as a tsunami ascent influx (ascending one km, but landwards !), caused by the fatal *AD*1755 Lisbon earthquake.

When keeping in mind that any distinction between the results of violent sedimentary events (that is, between tempestites, seismites, and tsunamites) in the Geological Past remains usually suggested rather than evidenced (see, e.g., Spalletta and Vai 1984, McAdoo and Watts 2004; and references therein), the presented analogies and resemblances allow to suggest a combined effect both of the synsedimentary seismic activity (origin of the Glanów Horst) and of the hurricane/storm surge (rubble transport) as the best explanation for the unusual structures studied.

Acknowledgements

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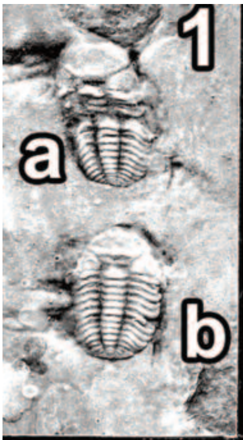
Manuscript submitted:
Revised version accepted:

PLATE 1

Early Famennian *Trimerocephalus* queues from the Holy Cross Mountains.

Shorter queues composed of up to five individuals: **1-3** – Smaller-sized individuals, **4-7** – Average-sized individuals; all × 3, further explanation in the text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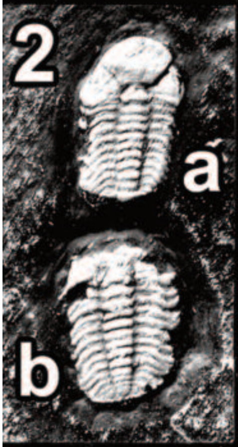
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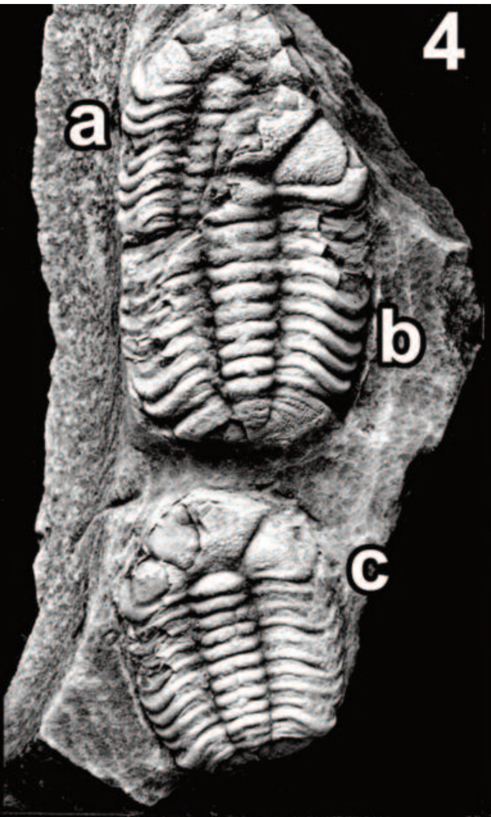
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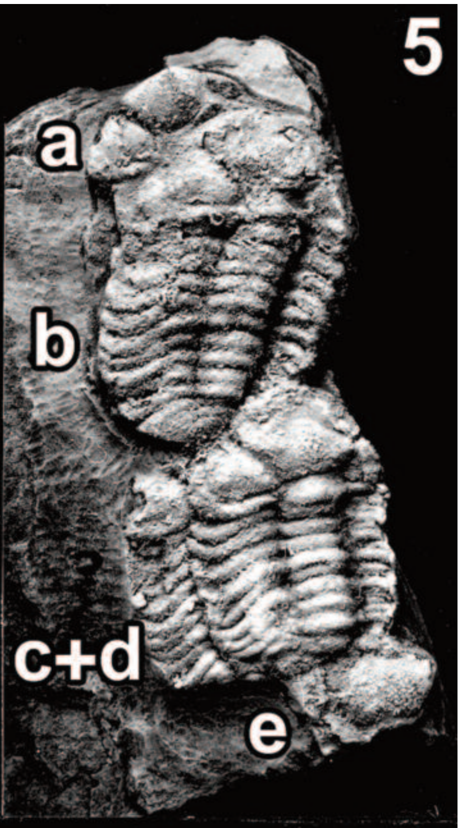
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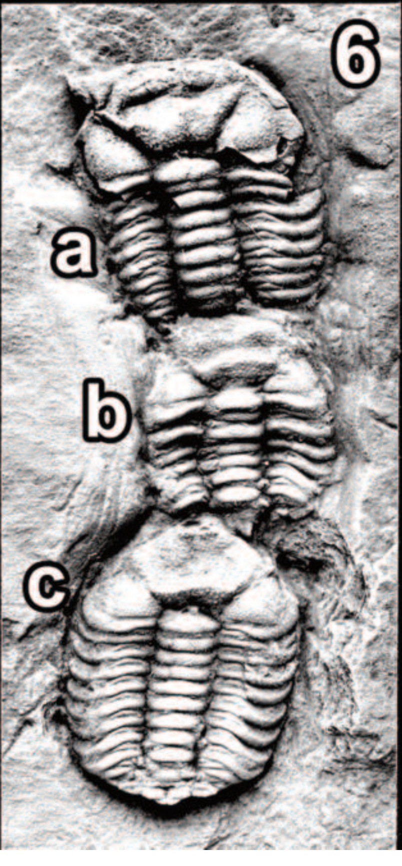
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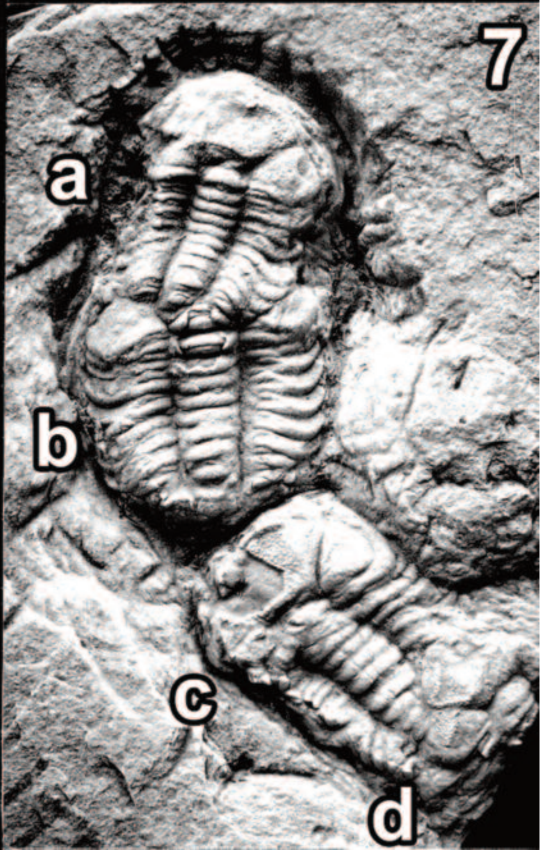
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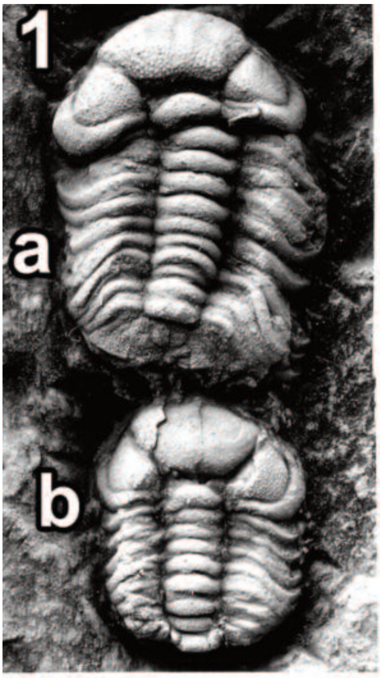
Plate 2

Early Famennian *Trimerocephalus* queues from the Holy Cross Mountains.

Variations in position and preservation of individuals within queues of shorter or longer extent; all × 3, further explanation in the text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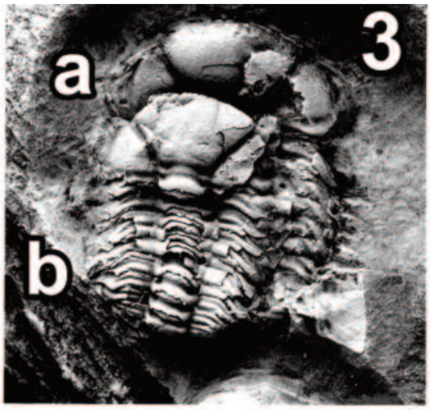
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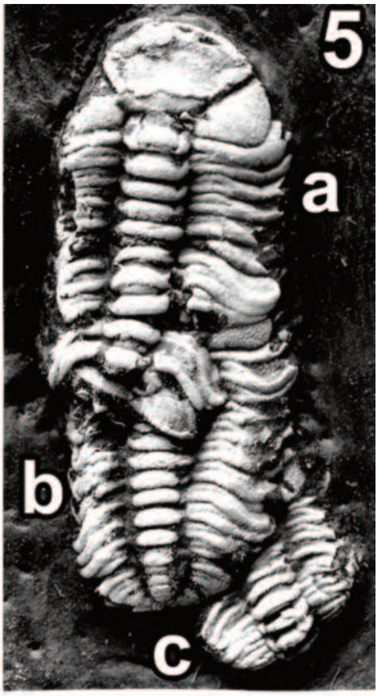
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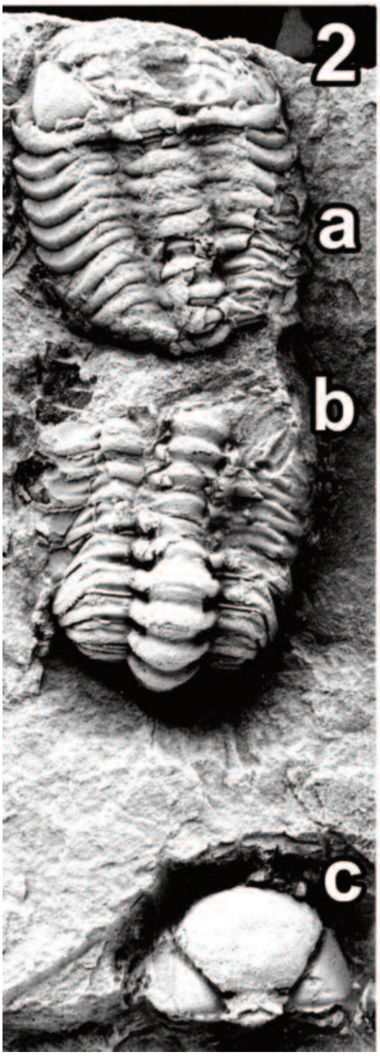
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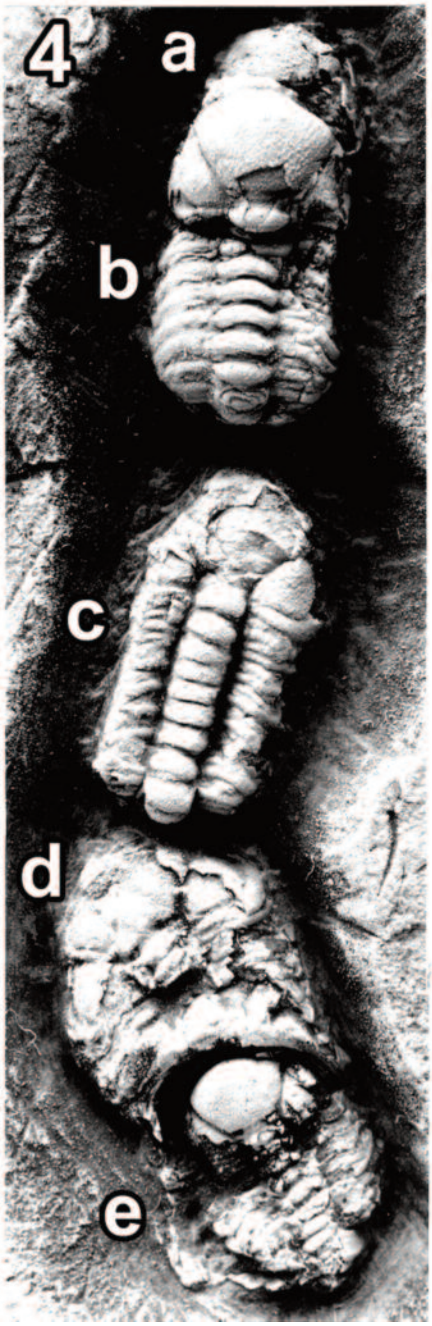
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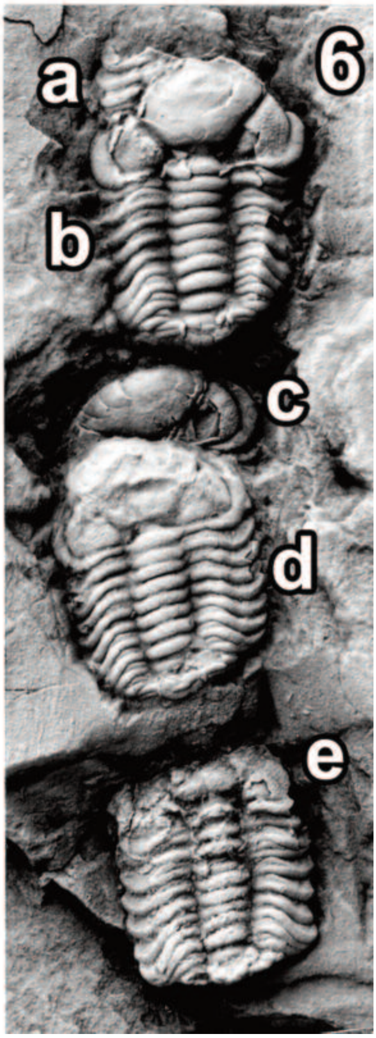
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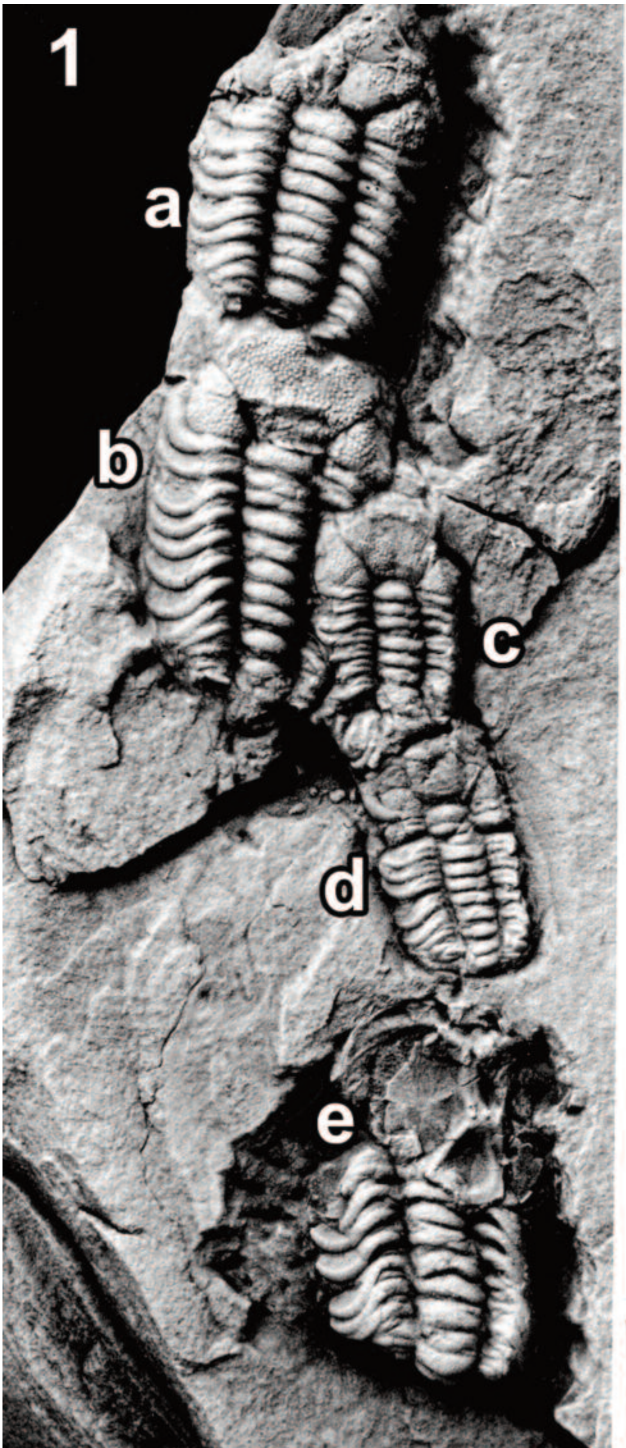
PLATE 3

Early Famennian *Trimerocephalus* queues from the Holy Cross Mountains.

Variations in the structure of longer queues: **1 –** Slightly disarrayed queue, **2 –** Queue of individuals oriented head-upon-tail (opisthocline), **3** – Jam of four individuals stacked one upon the other; all × 3, further explanation in the text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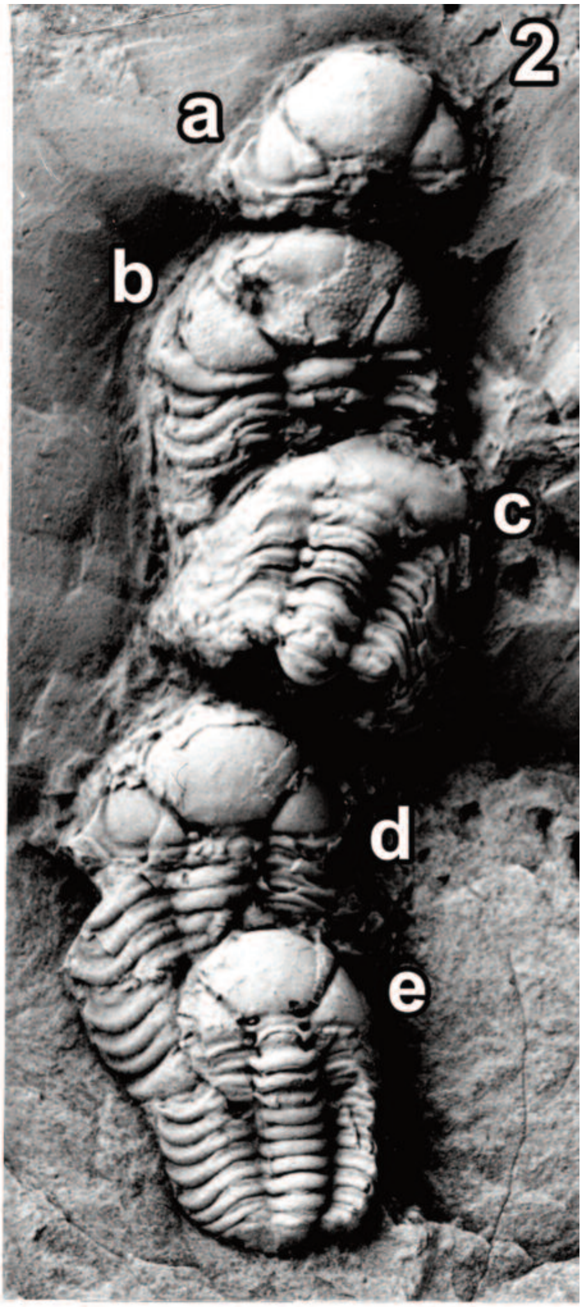
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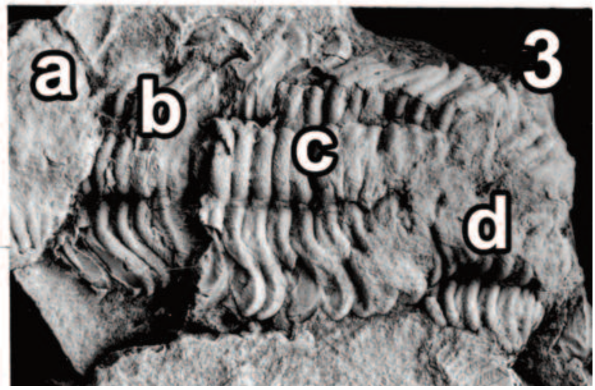
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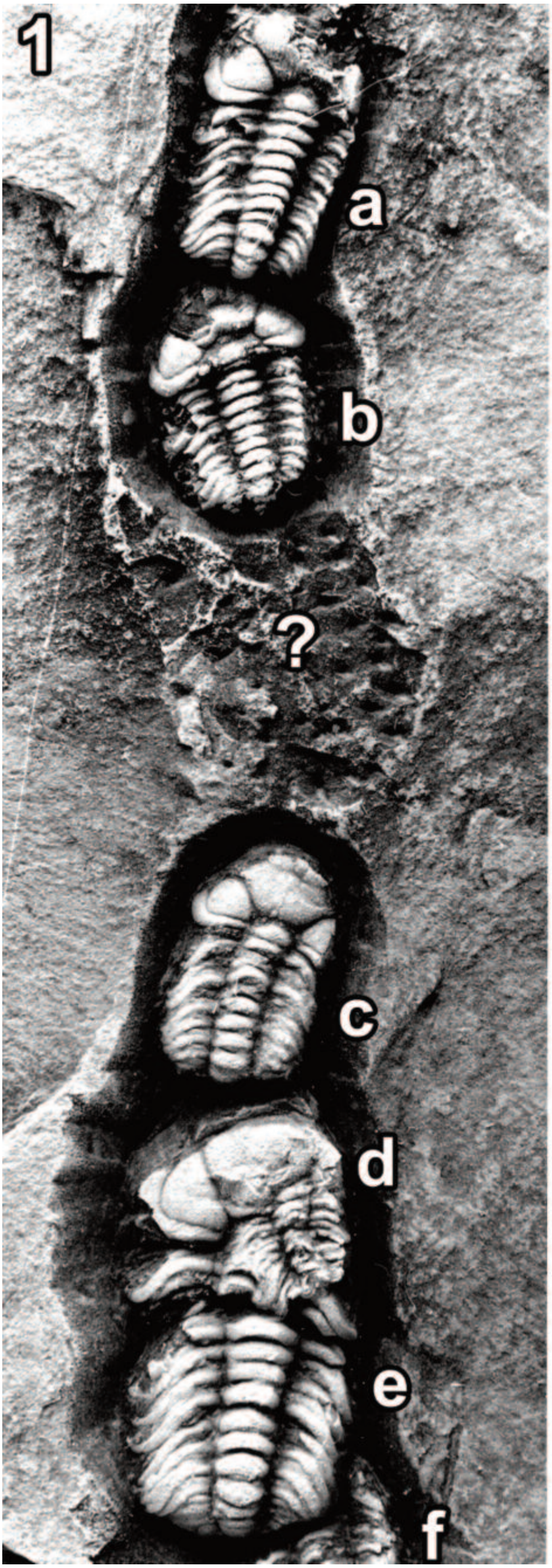
PLATE 4

Early Famennian *Trimerocephalus* queues from the Holy Cross Mountains.

Variations in the structure of longer queues: **1 –** Queue with one member absent, **2 –** Queue with a jam of three individuals to one side of the main file; all × 3, further explanation in the text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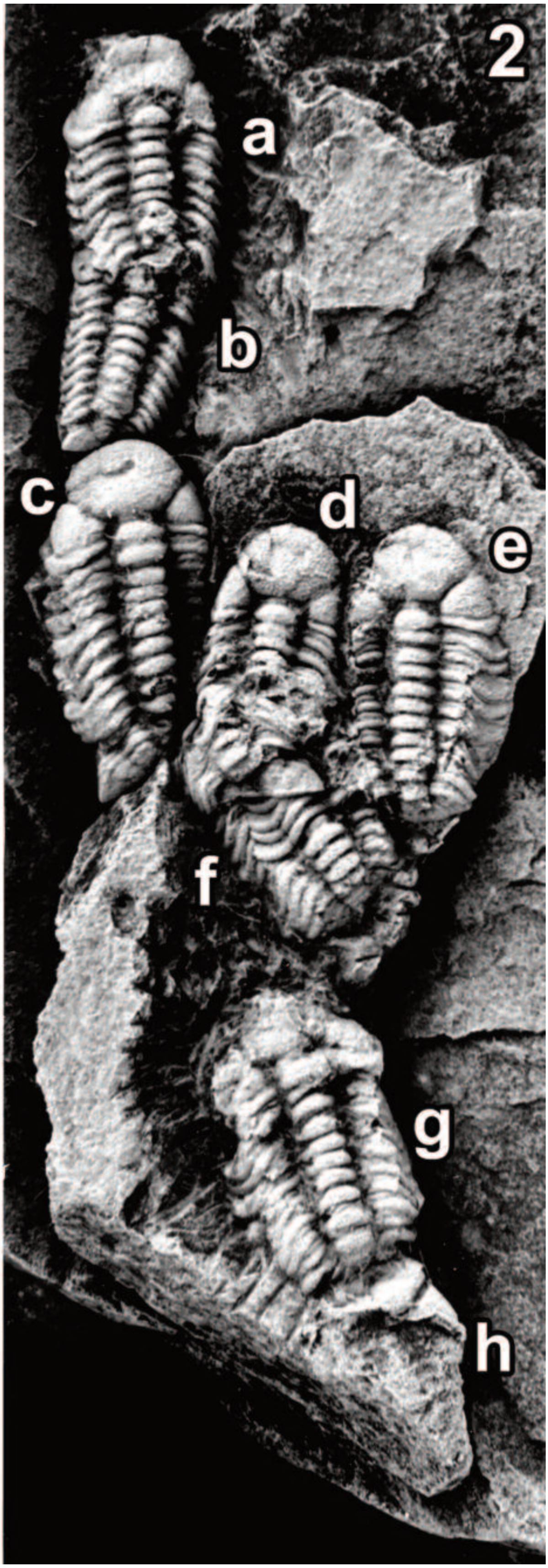
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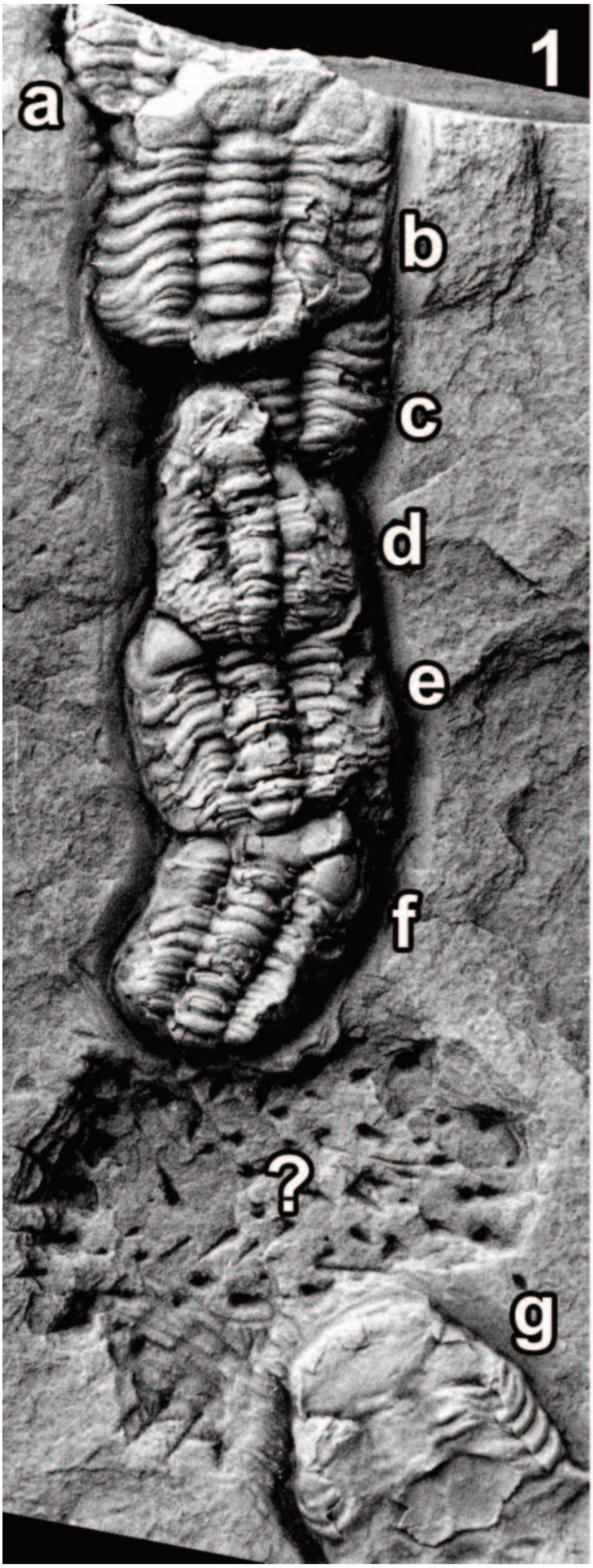
PLATE 5

Early Famennian *Trimerocephalus* queues from the Holy Cross Mountains.

Variations in the structure of longer queues: **1 –** Queue with most individuals oriented head-under-tail (prosocline), but one missing; Collection of Dr. T. Ochmański; **2** – Queue with a jam of two individuals disarrayed from the file, and with a vacant place for a missing individual; all × 3, further explanation in the text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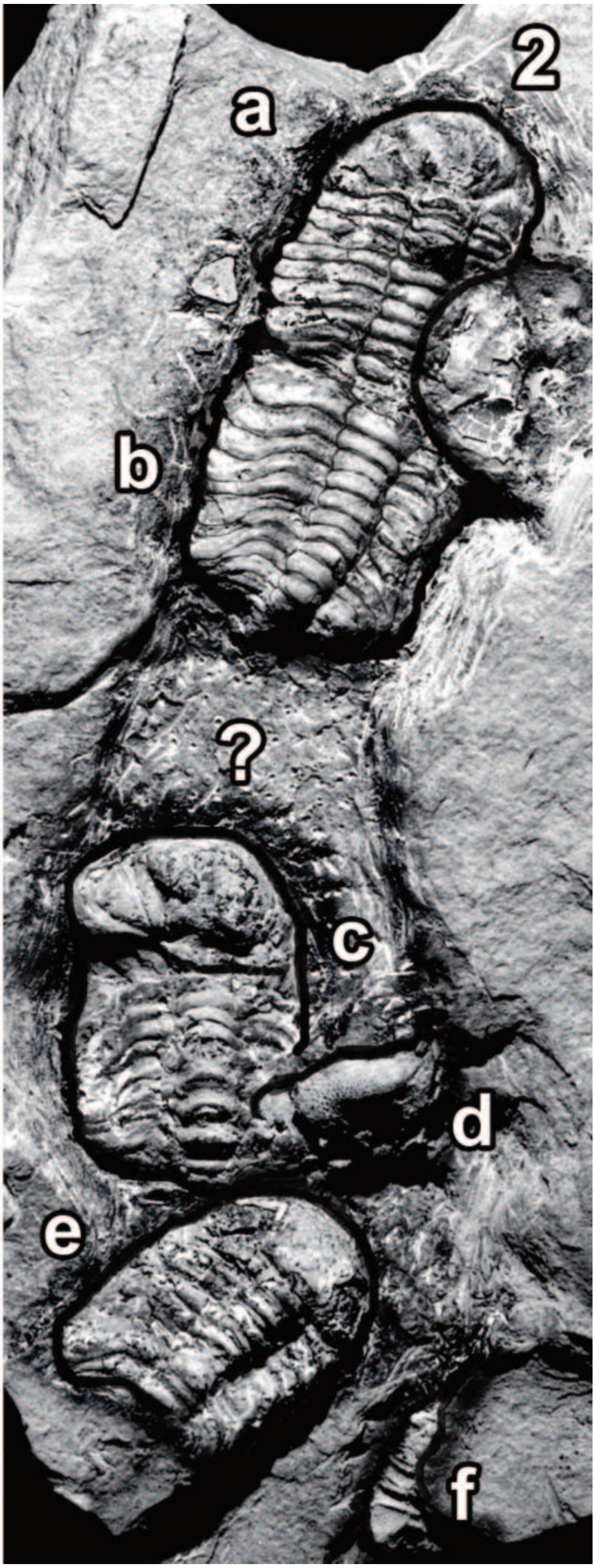
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